OFFICE OF NAVAL RESEARCH

END-OF-THE-YEAR REPORT

PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS/STUDENTS REPORT

for

GRANT or CONTRACT: N00014-93-1-0521

# COMPLEX DRIVING OF NONLINEAR SYSTEMS: THEORY AND EXPERIMENT

Professor William L. Ditto
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School of Physics
Georgia Institute of Technology
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7/29/98

Home of the 1996 Olympic Village
Georgia Institute of Technology

**Office of Contract Administration**
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August 12, 1998

In reply refer to: **G-41-697**

Mr. Michael F. Shlesinger, Code 1112
Office of Naval Research
800 North Quincy Street
Arlington, VA 22217-5660

Subject: **Annual Performance Report**
Project Director(s): William L. Ditto
Telephone No.: (404)894-5216
Contract No.: **N00014-93-1-0521**
Prime No.: **N/A**
**"PYI: COMPLEX DRIVING OF NONLINEAR SYSTEMS: THEORY & EXPERIMENT"**
Period Covered: 970701 through 980630

The subject report is forwarded in conformance with the contract/grant specifications.

Should you have any questions or comments regarding this report(s), please contact the Project Director or the undersigned at 404-894-4764.

**/TW**

Sincerely,

Wanda W. Simon

Wanda W. Simon
Reports Coordinator

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OFFICE OF NAVAL RESEARCH
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
PART I

PR Number:
Contract/Grant Number: N00014-93-1-0521
Contract/Grant Title: COMPLEX DRIVING OF NONLINEAR SYSTEMS: THEORY AND EXPERIMENT
Principal Investigator: William L. Ditto
Mailing Address: Applied Chaos Lab, School of Physics, Georgia Tech, Atlanta, GA 30332-0430
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a. Number of papers submitted to refereed journals, but not published: _2_
b. + Number of papers published in refereed journals (for each, provide a complete citation): _7_
c. + Number of books or chapters submitted, but not yet published: _2_
d. + Number of books or chapters published (for each, provide a complete citation): _0_
e. + Number of printed technical reports/non-refereed papers (for each, provide a complete citation): _0_
f. Number of patents filed: _2_
g. + Number of patents granted (for each, provide a complete citation): _3_
h. + Number of invited presentations (for each, provide a complete citation): _6_
i. + Number of submitted presentations (for each, provide a complete citation): _0_
j. + Honors/Awards/Prizes for contract/grant employees (list attached): _1_
(This might include Scientific Society Awards/Offices, Selection as Editors, Promotions, Faculty Awards/Offices, etc.)
k. Total number of Full-time equivalent Graduate Students and Post-Doctoral associates supported during this period, under this PR number: _2_
Graduate Students: _2_
Post-Doctoral Associates: _1_
including the number of,
Female Graduate Students: _0_
Female Post-Doctoral Associates: _0_
the number of
Minority* Graduate Students: _0_
Minority* Post-Doctoral Associates: _0_
and, the number of
Asian Graduate Students: _0_
Asian Post-Doctoral Associates: _0_
l. + Other funding (list agency, grant title, amount received this year, total amount, period of performance and a brief statement regarding the relationship of that research to your ONR grant)

### b. Papers published in refereed journals (7)

1. "Real-time experimental control of a system in its chaotic and nonchaotic regimes," D. Christini, V. In, M. L. Spano, W. L. Ditto and J. J. Collins, ***Phys. Rev. E.*** 56, R3749 (1997).
2. "Introduction: Control and synchronization of chaos," W. L. Ditto and K. Showalter, ***Chaos*** 7, 509 (1998).
3. "Maintenance of Chaos in a Computational Model of a Thermal Pulse Combustor," V. In, M. L. Spano, J. Neff, W. L. Ditto, C. Daw, K. D. Edwards and K. Nguyen, ***Chaos*** 7, 605 (1998).
4. "Control and Synchronization of Chaos in High Dimensional Systems: Review of Some Recent Results, M. Ding, E. Ding, W. L. Ditto, B. Gluckman, V. In, J. Peng, M. L. Spano and W. Yang, ***Chaos*** 7, 644 (1998).
5. "A method for visualization of ventricular fibrillation: design of a cooled fiberoptically coupled image intensified CCD data acquisition system incorporating wavelet shrinkage based adaptive filtering," F. X Witkowski, L. Joshua Leon, P. A. Penkoske, R. B. Clark, M. L. Spano, W. L. Ditto and Wayne R. Giles, ***Chaos*** 8, 94 (1998).
6. "Spatiotemporal evolution of ventricular fibrillation," Francis X. Witkowski, L. Joshua Leon, Patricia A. Penkoske, Wayne R. Giles, Mark L. Spano, William L. Ditto, & Arthur T. Winfree, ***Nature*** 392, pp. 78-82 (1998).
7. "Dynamics based Computation," Sudeshna Sinha and William Ditto (to appear Phys. Rev. Lett.)

### d. Books or chapters published (0)

### e. Printed technical reports/non-refereed papers (0)

### f. Patents filed (0)

### g. Patents granted (3)

1. "Suppression of Epileptiform Activity", B. Gluckman, M. L. Spano, S. Schiff and W. L. Ditto, U.S. Patent Pending (filed: 05/30/96, Serial Number 06/018606, granted awaiting number).
2. "Array Enhanced Stochastic Resonance," A. Bulsarsa, W. L. Ditto, J. Lindner, M. Inchiosa, B. Meadows, (U.S. patent accepted, awaiting number).
3. "Generalized Control of Chaos," M. Spano, W. L. Ditto, M. Ding, W. Yang, V. In and B. Gluckman, U.S. Patent accepted, awaiting number.

### h. Invited presentations (6)

1. "Low Dimensional Control of Chaos," International Summer School on Randomness and Nonlinearity, Uppsala, Sweden, August 18 - 22, 1997.
2. "Control of Human Cardiac Chaos," Dynamics Day, Duke University, Chapel Hill, NC, January 7 - 10, 1998.

3. "Spatial stochastic resonance: from analog VLSI to mammalian brains, "First International Conference on Stochastic Resonance In Biological Systems,"Arcidosso, Italy May 5-9, 1998.
4. "Applied Chaos: From Oxymoron to Reality," NASA Goddard Space Flight Center, Greenbelt, MD, May 22nd, 1998.
5. "Unstable Periodic Orbits – Tips, Traps and Techniques," SIAM 98, Toronto, CANADA, July 16th, 1998.
6. "Imaging and Control of Cardiac and Neural Systems," Gordon Research Conference on Bioelectrochemistry, Henniker, NH July 19-26, 1998.

## i. Submitted presentations (0)

## j. Honors/Awards/Prizes for contract/grant employees (1)

1. Granted Tenure (1997).

## j. Other funding

| | | | |
|---|---|---|---|
| "Spatially Extended Stochastic Resonance for Communications," | 2/98 - 2/99 | $75,000 | Naval Research & Development. |

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PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT
PART II

Principal Investigator: William L. Ditto
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ONR Program Officer: Dr. Michael Shlesinger

## Program Objective

To develop the theoretical, computer and engineering expertise to transition control and manipulation of chaos techniques and stochastic resoance into real world practical devices.

## Significant Results During Last Year.

We have developed a technique for controlling chaos in human atrial fibrillation with possible application towards the development of a very low energy atrial defibrillator. To aid in this work we have also developed a high speed, high resolution CCD imaging mapping system for the visualization and analysis of spiral wave dynamics during atrial and ventricular fibrillation in animal models. Additionally we have shown that stochastic resonance is exhibited by mammalian tissue and may indeed provide a mechanism by which neural tissue detects and is influenced by small scale signals in internal and external environments. We have also experimentally shown how DC electromagnetic fields can suppress seizure activity in hippocampal neuronal slices and thus may provide a novel way to suppress epileptic seizures in humans. We are also working on chaos control of an experimental pulse combustor in order to reduce emissions and increase efficiency of power generation equipment. Finally we have developed a technique by which distributed, coupled chaotic systems can perform computation. This exciting research may lay the groundwork for a novel computer design. The impact of our work on the maintenance and control of chaotic systems will impact both the medical and bioengineering communities (through potential new interventions for atrial and ventricular fibrillation, epilepsy and through new imaging techniques for excitable tissue) as well as the power generation and automobile communities (pulse combustor control). Additionally our demonstration of the ability of coupled chaotic systems to do computation may provide an alternative to conventional linear computer designs.

## Summary of Plans for Next Year's Work

We plan to fully characterize the spatio-temporal dynamics of atrial and ventricular fibrillation through our imaging project. We also will determine the spatial extent of chaos control in ventricular fibrillation and investigate multi-site chaos control in cardiac tissue. A chaos based computer will be constructed demonstrating how coupled chaos based computer will work in practice. Finally we will investigate how to use control to enhance systems demonstrating stochastic resonance.

## Names of Graduate Students and Post-Doctoral(s) Currently Working on Project

1. Joseph Neff (graduate student)
2. Josh Reiss (grad student)

3. Jonathen Mason (grad student)
4. Markus Loecher (post-doc)